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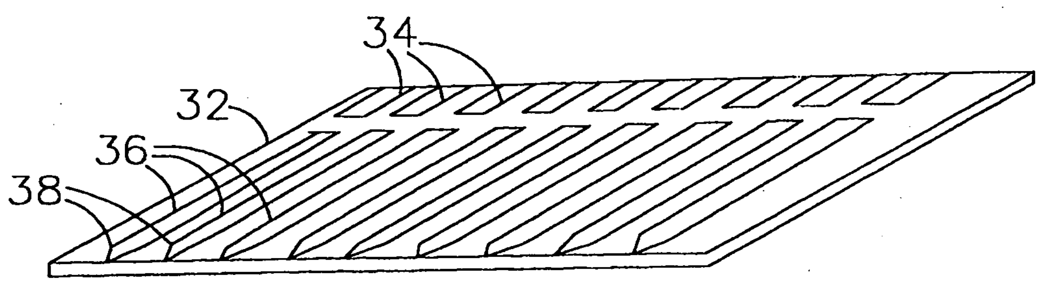

(57) Abstract

An apparatus and method for determining characteristics of a sample material utilize evanescent microwaves produced by one or more microstripline resonators. A plurality of microstripline resonators can be arranged in an array on a substrate (32) which can be passed across the surface of a sample to quickly determine characteristics of the sample material. Also, different sized or shaped resonators (36) can be arranged in an array to determine characteristics of a sample material at different depths within the material. Further, different resonator tip shapes (38) can be used to account for variations in a separation distance between the array and a sample material. A device employing the apparatus and methods can be used to determine electrical spin transitions in a sample material, to determine dopant profiles in a semiconductor, and to determine carrier lifetime or activation energies of a semiconductor substrate.

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MICROWAVE MEASURING INSTRUMENT AND METHODS OF MEASURING WITH MICROWAVES

BACKGROUND OF THE INVENTION

1. Field of the Invention

The invention is related to the use of evanescent microwaves to measure a sample material. In particular, the invention is related to a microstripline resonator assembly, and methods of using the assembly to measure or test sample materials.

2. Background of the Related Art

Evanescent waves have been used in various measuring instruments to measure extremely small features. For instance, evanescent optical and microwave fields are both used in high resolution imaging of materials. Such evanescent waves can be used in both a reflection or a transmission mode.

In the microwave regime, evanescent fields can be produced by drilling a small hole in a waveguide. Alternatively, such evanescent microwaves can be produced at the terminal end of a transmission line. Figure 1 shows a microstripline resonator 30 on a substrate 32. The microstripline resonator 30 includes a feed line 34 and a resonator portion 36 having a tapered tip 38. Figure 2 shows how the different portions of the microstripline resonator are formed on a top surface of the substrate 32.

When the length L of the transmission line is equal to an odd number of quarter wavelengths, a resonant structure will be formed. Evanescent microwaves are generated at the tip 38 of the microstripline resonator 30. As shown in Figure 2, when the microstripline resonator 30 is brought adjacent a sample material S, the electrical field output at the tip 38 of the resonator will interact with the sample material S. This can effect the electrical characteristics of the microstripline resonator, such as its Quality Factor (Q) and its resonant frequency.

Figure 3 shows the relationship between the electrical field strength E and the distance from the end of the tip 38 of the microstripline resonator. As the separation distance d between the tip 38 of the microstripline resonator and the sample material S increases, the strength of the electrical field f decreases.

Various electrical models can be used to characterize and explain the relationship between the electrical characteristics of the microstripline resonator, and the interaction with the sample material. There are two theoretical models that can be used.

In the first model, we treat the microstripline resonator as an ideal loss-less microstripline and a short length of current carrying wire 42, as shown in Figure 4A. Using this model, one can assume that all the probe fields are generated around the short wire 42. This configuration is typically referred to as a magnetic dipole probe because the current traveling through the wire 42 generates a magnetic field.

A second theoretical model is shown in Figure 4B. In this instance, the wire 44 at the end of the microstripline resonator is open. This is typically referred to as an electric dipole probe configuration.

Using either the magnetic or electric dipole probe configuration, one can then calculate the magnetic and electric fields surrounding the tip of the microstripline resonator. The electromagnetic field strength will vary for different positions surrounding the probe tip. Figure 6 shows a plurality of arrows 39 which indicate a field strength for different positions around the tip of a microstripline resonator 30.

To study the interaction between this electrical field and a sample material, one can treat the probe as an electrically short antenna (i.e., its length is shorter than the wavelength) that is placed near a dissipating medium. One can then calculate a reflection coefficient of the resonator, which can be actually detected in the resonator. The reflection coefficient will vary depending upon the electrical characteristics of the sample material.

Figure 5 shows a microstripline resonator 30 that includes a feed line 34 and a resonator portion 36 having a tapered tip 38, all of which are formed on a substrate 32. Figure 5 shows how the electrical characteristics of the microstripline resonator, and its interaction with the sample material, can be explained using electrical circuit components. As shown in Figure 5, the coupling between the feed line 34 and the resonator portion 36 can be modeled as a first capacitor C_1. One could also have a second capacitor C_2 between the resonator portion 36 and a ground plane. The coupling between the tip 38 of the resonator and the sample material can be modeled as a third capacitor C_3. The actual electrical characteristics of the sample material can be modeled as a resistor R_S and a capacitor C_S in parallel.

By monitoring the reflection coefficient of a microstripline resonator, as the resonator is brought in close proximity to a sample material, one can determine characteristics of the sample material. Figure 7 shows the reflection coefficient curves for a microstripline resonator at different activation frequencies. The curve 48 indicates the reflection coefficient of the microstripline resonator when nothing surrounds the tip of the resonator. Under these conditions, a resonant frequency occurs at 1 GHz. When the tip of the microstripline resonator is brought in close proximity to a copper sample material, the reflection coefficient is given by the curve 50. As can be seen in Figure 7, the proximity of the copper sample material shifts the resonant frequency to approximately 1.08 GHz.

Figure 8 shows the resonance curve for a microstripline resonator when it was placed adjacent two different types of materials. The curve 52 represents a resistive sample, whereas the curve 54 represents a conductive metallic sample. One can use the dependence of the resonant frequency of a microstripline resonator on the electrical characteristics of the sample material, to characterize unknown sample materials. Also, by monitoring the reflection coefficient of a microstripline resonator as it is

passed across the surface of the sample material, one can determine whether the electrical characteristics of the sample material vary. This process can be used to scan a sample material for defects, residual stresses, or subsurface features.

SUMMARY OF THE INVENTION

The invention is a microstripline resonator array that can be used to characterize sample materials. The microstripline resonator array can have various shapes which are useful for sensing the characteristics of various shapes of sample materials. The resonator array assembly can be contained within a housing which protects the assembly from detrimental environmental conditions. The housing would have a window which would allow the electrical fields produced by each of the microstripline resonators to interact with a sample material, while still protecting the resonator array from the environment.

Embodiments of the invention could includes microstripline resonator arrays where the individual microstripline resonators have different tip configurations. The electrical characteristics of the different tipped resonators can be used to account for variations in a separation distance between the resonator array and a sample material.

Also, embodiments of the invention could have microstripline resonator arrays where each of the microstripline resonators have a different resonator length. The different resonator length will give rise to a different electromagnetic frequency, which in turn results in a different penetration depth into a sample material. Thus, each of the microstripline resonators can be used to probe a sample material at a different distance below the surface of the sample material. An array of microstripline resonators of varying lengths can allow one to calculate or create a profile of the characteristics of the sample material at different depths.

One or more microstripline resonators could also be used in an apparatus embodying the invention that is designed to monitor electronic spin transitions in a sample material. The assembly would include a device for applying a magnetic field

to the sample material, as well as a microstripline resonator, or an array of microstripline resonators. Variations in the magnetic field, or in the frequency of the electromagnetic emissions from the resonator, can be used to induce electronic spin transitions in the sample material. The occurrence of the spin transitions can be detected by variations in the electrical characteristics of the microstripline resonator.

Embodiments of the invention can be used to sense or to measure doping profiles, carrier lifetime and activation energies of the sample semiconductor material.

Additional advantages, objects, and features of the invention will be set forth in part in the description which follows and in part will become apparent to those having ordinary skill in the art upon examination of the following or may be learned from practice of the invention. The objects and advantages of the invention may be realized and attained as particularly pointed out in the appended claims.

BRIEF DESCRIPTION OF THE DRAWINGS

A detailed description of preferred embodiments of the present invention will be described in conjunction with the following drawing figures, wherein like elements are referred to with like reference numbers, and wherein:

Figure 1 is a perspective diagram of a microstripline resonator formed on a substrate;

Figure 2 is a side view of a microstripline resonator on a substrate adjacent a sample material;

Figure 3 is a graph showing the electrical field strength of a microstripline resonator for different distances from the tip of the resonator;

Figures 4A and 4B show alternate models for describing the electrical characteristics of a microstripline resonator;

Figure 5 shows how a microstripline resonator and a sample material can be modeled with electrical components;

Figure 6 is a diagram showing the electrical field strength of a field generated adjacent a tip of a microstripline resonator;

Figure 7 is a chart showing changes in the reflection coefficient of a microstripline resonator when it is adjacent different materials;

Figure 8 is a diagram showing changes in the reflection coefficient of a microstripline resonator when it is adjacent a resistive material and a conductive material;

Figure 9 is a perspective diagram of a microstripline resonator array;

Figure 10 is a plan view of a microstripline resonator array arranged in a semicircle;

Figure 11 is a diagram of a microstripline resonator inside a housing;

Figure 12 is a plan view of a microstripline resonator assembly on a substrate;

Figure 13 is a diagram of a microstripline resonator array, wherein the microstripline resonators have different tip configurations;

Figure 14 is a diagram of a microstripline resonator array, wherein different microstripline resonators have different lengths;

Figure 15 is a diagram of an apparatus that can be used to scan a microstripline resonator array across the surface of a sample material or to measure carrier lifetime and activation energies of a semiconductor material; and

Figure 16 is a diagram of an apparatus that can be used to sense electronic spin transitions in a sample material.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

A microstripline resonator array embodying the invention is shown in Figure 9. The array includes a plurality of microstripline resonators formed on the top surface of a substrate. Each microstripline resonator array includes a feed line 34, a resonator portion 36, and a tip portion 38. The tip portions 38 can have a variety of different configurations, as will be described more fully below. The array shown in

Figure 9 would be ideal for detecting characteristics of a sample material having a flat surface.

Figure 10 shows a plan view of an alternate embodiment of a microstripline resonator array, wherein the resonators are arranged in a semicircle. In this embodiment, a semicircular portion 56 is removed from the substrate. This embodiment would be ideal for measuring characteristics of a curved or circular sample material.

Figure 11 shows a microstripline resonator array inside a protective housing 60. The housing would have a window 62, formed of a suitable material, which allows the electrical fields generated by the tips 38 of the microstripline resonators to pass through the housing and to interact with a sample material. The window 62 of the housing 60 could be formed from aluminum, Teflon, diamond-like films, GaN, or other suitable materials. Ideally, the housing 60 should prevent dust particles or other potentially hazardous material from reaching the microstripline resonator array.

Figure 12 shows a slightly more detailed view of the microstripline resonator formed on a substrate 32. The device includes an RF source 66 coupled to a circulator 64. The circulator 64 is also connected to a detector 68. The circulator 64 couples RF energy from the RF source 66 into the feed line 34, and thus the actual resonator section 36. The detector 68 can be used to monitor the electrical characteristics of the resonator assembly. All of these features can be formed on a single integrated circuit chip. A plurality of microstripline resonator assemblies, like the one shown in Figure 12, can be incorporated into an array as shown in Figures 9-11.

A microstripline resonator array embodying the invention can be used to determine doping profiles of a semiconductor substrate. The array would be placed near the surface of the semiconductor substrate, and the array would then be moved along the surface of the substrate. The electrical characteristics of each of the microstripline resonators in the array would be monitored as the array passes over different portions of the substrate. Variations in the electrical characteristics of the

individual microstripline resonators would indicate a variation in the doping concentration within the substrate. By using a particular microstripline resonator with a semiconductor sample having known doping characteristics, one can create a calibration curve for the microstripline resonator. The calibration curve could then be used in conjunction with measurement results obtained for unknown semiconductor substrates to determine the actual doping profile of the unknown substrates.

Because the strength of the electrical field produced at the tip of each microstripline resonator varies (decreases) with greater distances from the probe tip, the separation distance between the sample material and the probe tip has a great influence on the interaction between the probe and the sample material. Thus, a microstripline resonator array embodying the invention is sensitive to variations in the separation distance. This can be problematic if the surface under examination is not uniform, or if it is difficult to pass the array across the surface at a substantially constant separation distance.

However, it is possible to perform differential measurements using two different microstripline resonators to reduce the sensitivity to variations in separation distance. In the embodiment shown in Figure 13, two different microstripline resonators are used to sense the characteristics of a sample material S. The first microstripline resonator has a tapered tip 38b. The second microstripline resonator has a substantially flat tip 38b. The output of both microstripline resonators will be dependent upon the separation distance, however, the dependence will be different due to the different probe tip configurations. Taking a ratio of the probe outputs provides a way to compensate for separation distance variations.

Also, it is known that the penetration depth of a microwave signal inside a sample material is inversely proportional to the square root of the frequency of the signal. Thus, different frequency microwaves will penetrate a sample material to different depths. Because the microstripline resonators used in the present invention

have a resonant frequency which is dependent upon the length of the resonator section 36, it is not possible to selectively vary the frequency of the microwaves generated. However, it is possible to create a microstripline resonator array with different length resonator sections, as shown in Figure 14. The different length resonator sections result in different frequency microwaves generated at the tips. This in turn, gives rise to different penetration depths within the sample material.

The microstripline resonator array shown in Figure 14 can be used to determine characteristics of a sample material at a plurality of different depths. For instance, the array could be passed over the surface of a sample material a plurality of times so that each of the microstripline resonators passes over the same locations. For instance, during a first pass, the tip 38a of the first microstripline resonator would pass over a particular location on the sample material. During a subsequent pass, the tip 38b of a second microstripline resonator would pass over the same location. Due to their different operating frequencies, the waves produced by each of the two microstripline resonators would penetrate to a different depth. Thus, the detected electrical characteristics of the microstripline resonators would give an indication of characteristics of the sample material at different depths under the interrogated location. This type of multiple pass approach could be used to generate a three dimensional doping profile for a semiconductor substrate.

In alternate embodiments, the array shown in Figure 14 could also be used to help eliminate problems caused by a variation in the separation distance.

A microstripline resonator array embodying the invention could also be used to determine carrier lifetime and activation energies of a semiconductor substrate. Because the microwave probe response is very fast, it can be used to sense time varying characteristics of a substrate. To determine carrier lifetime, or activation energy characteristics of a substrate, the substrate could be perturbed with an external stimulus such as an optical pulse or a high power electromagnetic pulse. A microstripline resonator array could then monitor the recovery of the semiconductor

surface after the perturbing energy is removed. The sensed electrical characteristics of the resonators could then be used to determine carrier lifetime or activation energies.

An apparatus that can be used to scan a microstripline resonator array embodying the invention across the surface of a sample material is shown in Figure 15. The sample material S is mounted on a movable table 82. A microstripline resonator array 60 is held in a fixation unit 84 of a movable arm 86. In the embodiment shown in Figure 15, the movable arm 86 is capable of moving the fixation portion 84 toward and away from the surface of the table 82 in the direction of arrows 90. The movable table 82 is capable of moving in the directions shown by the arrows 92. Thus, the microstripline resonator array 60 would be moved into close proximity with the sample material S by the movable arm 86. The movable table 82 could then move with respect to the microstripline resonator array 60 to accomplish the scanning action. In alternate embodiments, the table could be movable in the direction of the arrows 90, and the movable arm 86 could be movable in the direction of arrows 92. In still other embodiments, the movable arm 86 could be capable of moving in all three axes, and the sample material could remain fixed. In still other embodiments, the sample material could be movable in all three axes, and the microstripline resonator array 60 could remain fixed.

The apparatus shown in Figure 15 could be used to determine doping profiles of a semiconductor substrate as described above. Alternatively, this apparatus could be used to determine carrier lifetime and activation energies of a semiconductor substrate using a perturbing apparatus 91 which can be used to deliver a pulse of electromagnetic radiation to a surface of the substrate. As mentioned above, the perturbing pulse could be an optical pulse, or an electromagnetic pulse.

Another apparatus embodying the invention that can be used to determine electrical spin transitions of a sample material is shown in Figure 16. The apparatus includes a magnetic device 94 for applying a magnetic field to a sample material S. Typically, the magnetic device 94 would include two opposed arms 98, 99 and the

magnetic field would be generated between the two arms 98, 99. The sample material S would be placed between the two arms 98, 99, and a microstripline assembly 30 would be located adjacent a surface of the sample material S.

In a first approach, the magnetic device would apply a substantially constant magnetic field to the sample material S. The frequency of the microwave emissions from the microstripline resonator would then be varied. Whenever the microwave photon energy output by the microstripline 30 becomes equal to the transition energy of the spin, a transition would occur, which would absorb energy from the microwave field. The spin transition would alter an electrical characteristic of the microstripline resonator, which would be sensed by a detector of the device. Since it may be difficult to vary the frequency of the emissions of a microstripline resonator, the assembly 30 could include a plurality of microstripline resonators, each of which is constructed to output different frequency emissions. The different microstripline resonators could be selectively energized until one of the resonators causes an electrical spin transition.

In a second approach, the microwave frequency of the microstripline resonator would be kept substantially fixed, and the magnetic field produced by the magnetic device 94 would be varied. The varying magnetic field would alter the spin transition energy, and when the transition energy coincides with the microwaves photon energy, a transition would occur. Again, the transition would be sensed by sensing electrical characteristics of the microstripline resonator.

Many variations of the above described apparatus are possible without departing from the spirit and scope of the invention. For instance, microstripline resonator arrays embodying the invention could have a variety of different physical shapes and sizes for determining the characteristics of different sample materials. Also, any individual microstripline resonator array could have a plurality of different microstripline resonators within the array. The resonators could vary by their tip configuration, or their resonator width or length. Also, although the microstripline resonator arrays shown in Figures 9 and 10 are all formed on a single substrate,

multiple substrate arrays could also be created.

Methods of using the resonator arrays, as described above, need not use the exact microstripline resonator array configuration shown in the figures of the present application. Many different resonator configurations are possible. Any resonator structure that outputs evanescent microwaves that are useful for determining characteristics of a sample material can be used in methods embodying the present invention.

The foregoing embodiments are merely exemplary and are not to be construed as limiting the present invention. The present teaching can be readily applied to other types of apparatuses. The description of the present invention is intended to be illustrative, and not to limit the scope of the claims. Many alternatives, modifications, and variations will be apparent to those skilled in the art. In the claims, means-plus-function clauses are intended to cover the structures described herein as performing the recited function and not only structural equivalents but also equivalent structures.

WHAT IS CLAIMED IS:

1. An microwave measuring instrument, comprising:

a housing; and

a plurality of microstripline resonators arranged on the housing, wherein each of the microstripline resonators produce electromagnetic radiation, and wherein at least two of the plurality of microstripline resonators have different configurations.

2. The instrument of claim 1, wherein the at least two microstripline resonators produce different frequencies of electromagnetic radiation.

3. The instrument of claim 1, wherein the at least two microstripline resonators are configured to sense characteristics of a target object at different depths within the target object.

4. The instrument of claim 1, further comprising a plurality of detectors, wherein each detector is coupled to a corresponding microstripline resonator, and wherein each detector is configured to sense at least one of a quality factor and a resonance frequency of the microstripline resonator to which it is coupled.

5. The instrument of claim 1, wherein each microstripline resonator comprises:

a feedline; and

a resonator portion coupled to the feedline.

6. The instrument of claim 5, wherein the resonator portion of each microstripline resonator comprises at least one of a quarter-wavelength resonator and a half-wavelength resonator.

7. The instrument of claim 5, wherein the resonator portions of the at least two microstripline resonators have different lengths.

8. The instrument of claim 5, wherein the feedline of each microstripline resonator comprises:

a source of electromagnetic radiation;
a circulator coupled to the source of electromagnetic radiation; and
a launcher coupled to the circulator.

9. The instrument of claim 1, wherein the plurality of microstripline resonators are arranged such that sensing ends of the resonators are substantially aligned in a straight line.

10. The instrument of claim 1, wherein the plurality of microstripline resonators are arranged such that sensing ends of the resonators are substantially aligned in a curve.

11. The instrument of claim 1, wherein the instrument is configured to compensate for variations in a separation distance between the instrument and a surface of a target object as the instrument is scanned across the surface of the target object.

12. The instrument of claim 11, wherein the at least two microstripline resonators each include a resonator portion having a sensing tip, and wherein the shapes of the sensing tips of the at least two microstripline resonators are different.

13. The instrument of claim 11, wherein the instrument is configured to output a measurement signal that represents a ratio of signals produced by the at least two microstripline resonators.

14. A measuring instrument for sensing electronic spin transitions, comprising:

a magnetic device for applying a magnetic field to a sample; and

a microstripline resonator assembly, wherein the instrument is configured to sense an electronic spin transition of the sample.

15. The instrument of claim 14, wherein the instrument is configured to selectively vary a frequency of electromagnetic radiation produced by the microstripline resonator assembly while the magnetic field applied by the magnetic device remains substantially constant.

16. The instrument of claim 15, wherein the microstripline resonator assembly comprises a plurality of microstripline resonators, and wherein different ones of the microstripline resonators produce electromagnetic radiation at different frequencies.

17. The instrument of claim 14, wherein the instrument is configured to vary the magnetic field applied to the sample while a frequency of electromagnetic radiation produced by the microstripline resonator assembly remains substantially constant.

18. The instrument of claim 14, wherein the instrument is configured to sense at least one of a quality factor and a resonant frequency of the microstripline resonator assembly.

19. The instrument of claim 14, wherein the instrument is configured such that a variation in at least one of a quality factor and a resonant frequency of the microstripline resonator assembly is indicative of an electronic spin transition of the sample.

20. A measuring instrument for sensing characteristics of a semiconductor, comprising:

a housing; and

a microstripline resonator assembly arranged on the housing, wherein the instrument is configured to measure doping profiles of a sample semiconductor.

21. The instrument of claim 20, further comprising a detector configured to sense characteristics of the microstripline resonator assembly, and wherein the sensed characteristics of the microstripline resonator assembly provide an indication of a dopant concentration in a sample semiconductor positioned adjacent the microstripline resonator assembly.

22. The instrument of claim 21, wherein the instrument is configured to scan the at least one microstripline resonator assembly across a surface of the sample semiconductor, and wherein the instrument is configured to output the sensed characteristics of the microstripline resonator assembly to a recording device as the instrument is scanned across the sample semiconductor.

23. The instrument of claim 20, wherein the microstripline resonator assembly comprises a plurality of microstripline resonators.

24. The instrument of claim 23, wherein the plurality of microstripline resonators have different configurations.

25. The instrument of claim 23, wherein the plurality of microstripline resonators are configured to sense dopant concentrations in a sample semiconductor at different depths.

26. The instrument of claim 23, wherein the plurality of microstripline resonators produce electromagnetic radiation having different frequencies.

27. A measuring instrument for sensing characteristics of a semiconductor, comprising:

a housing; and

a microstripline resonator assembly arranged on the housing, wherein the instrument is configured to measure at least one of carrier lifetime and activation energies of a sample semiconductor.

28. The instrument of claim 27, further comprising at least one detector configured to sense characteristics of the microstripline resonator assembly, wherein the sensed characteristics of the microstripline resonator assembly provide an indication of at least one of carrier lifetime and activation energies of a sample semiconductor.

29. The instrument of claim 28, wherein the instrument is configured to output the sensed characteristics of the microstripline resonator assembly to a recording device while the sample semiconductor is subjected to a perturbing stimulus.

30. The instrument of claim 29, wherein the instrument is configured to output the sensed characteristics of the microstripline resonator assembly to a recording device while the sample semiconductor is subjected to an electromagnetic pulse.

31. The instrument of claim 29, wherein the instrument is configured to output the sensed characteristics of the microstripline resonator assembly to a recording device while the sample semiconductor is subjected to an optical pulse.

32. The instrument of claim 27, wherein the microstripline resonator assembly comprises a plurality of microstripline resonators.

33. The instrument of claim 32, wherein the plurality of microstripline resonators have different configurations.

34. The instrument of claim 32, wherein the plurality of microstripline resonators are configured to sense at least one of carrier lifetime and activation energy at different depths in the sample semiconductor.

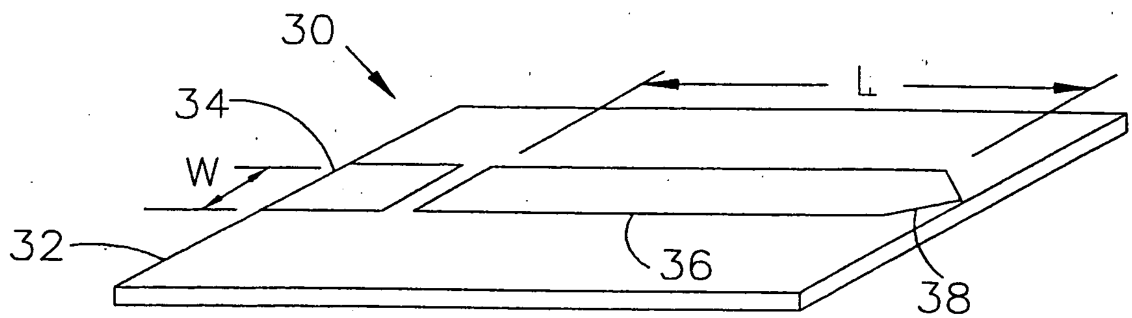

FIG. 1

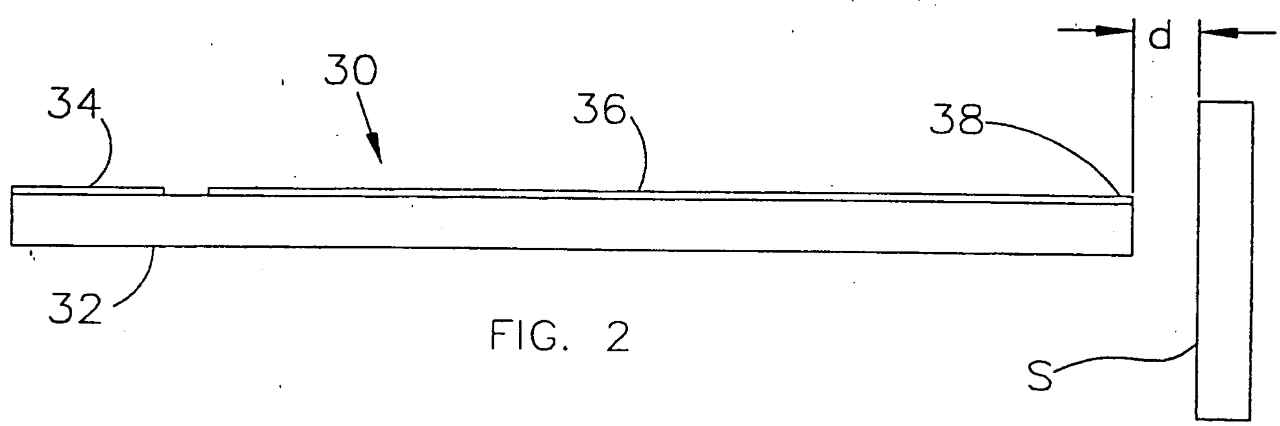

FIG. 2

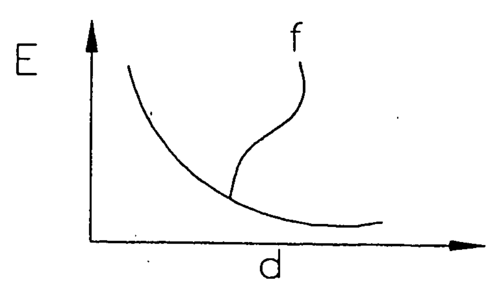

FIG. 3

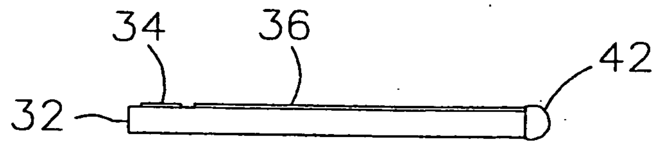

FIG. 4A

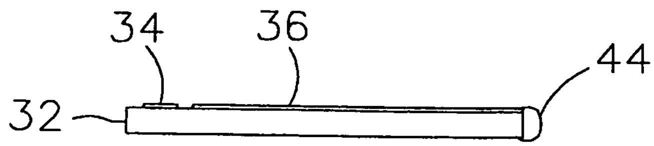

FIG. 4B

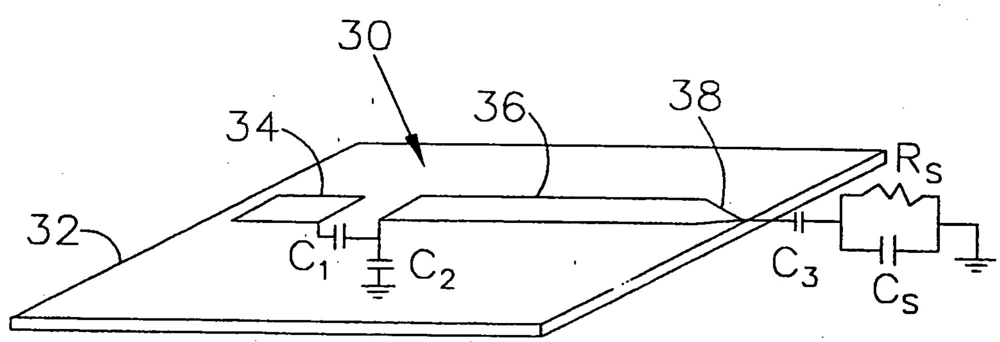

FIG. 5

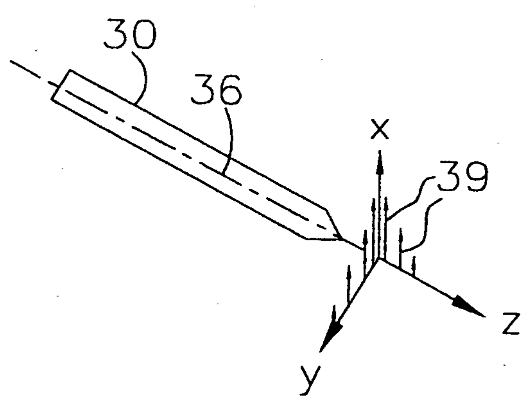

FIG. 6

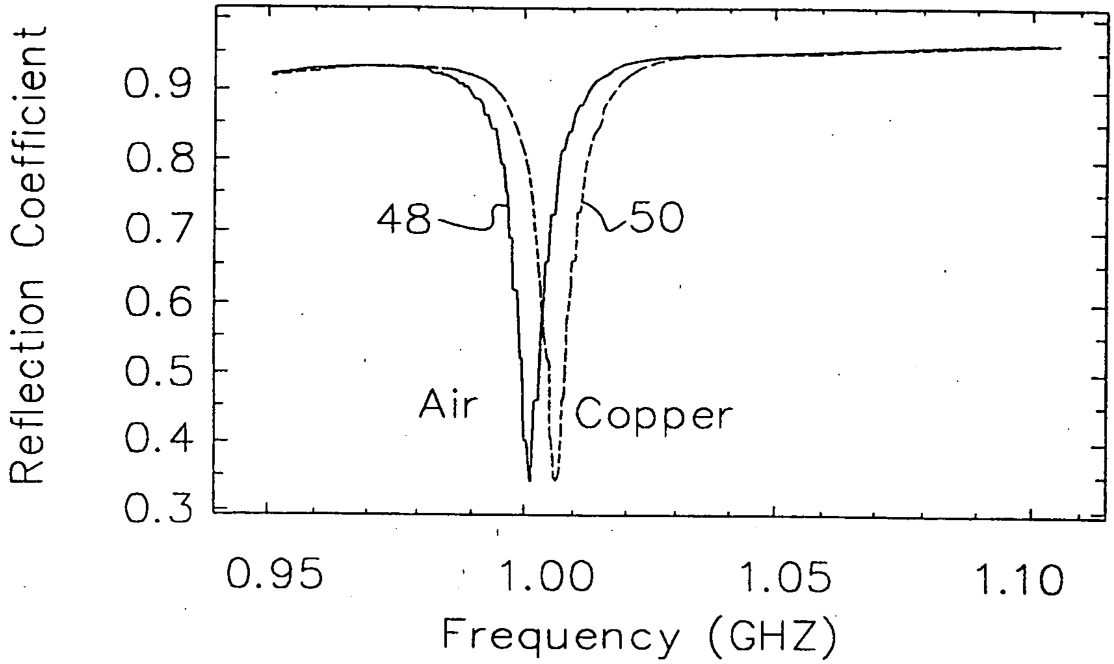
Reflection Coefficient
0.9
0.8
0.7
0.6
0.5
0.4
0.3
48
50
Air
Copper
0.95
1.00
1.05
1.10
Frequency (GHZ)

FIG. 7

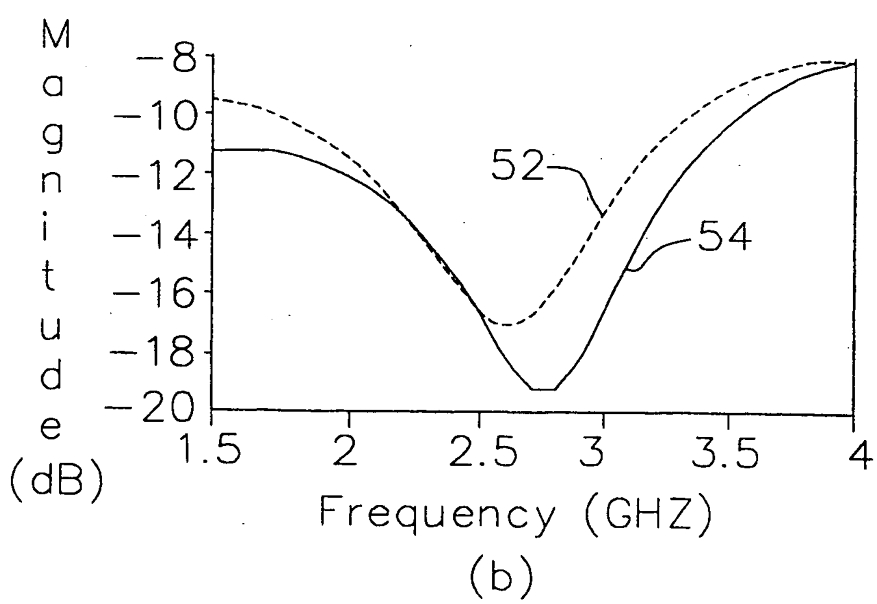
Magnitude (dB)
-8
-10
-12
-14
-16
-18
-20
52
54
1.5
2
2.5
3
3.5
4
Frequency (GHZ)
(b)

FIG. 8

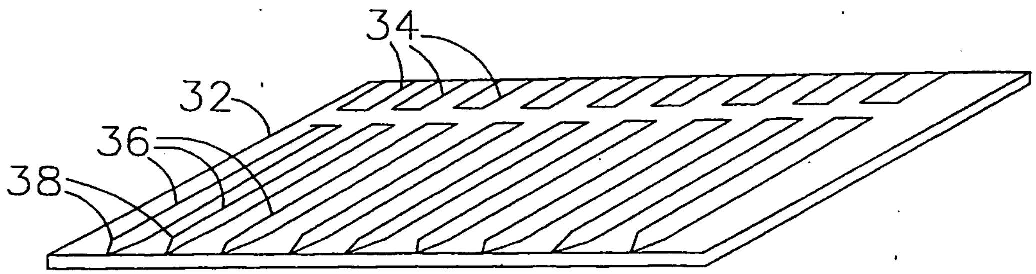

FIG. 9

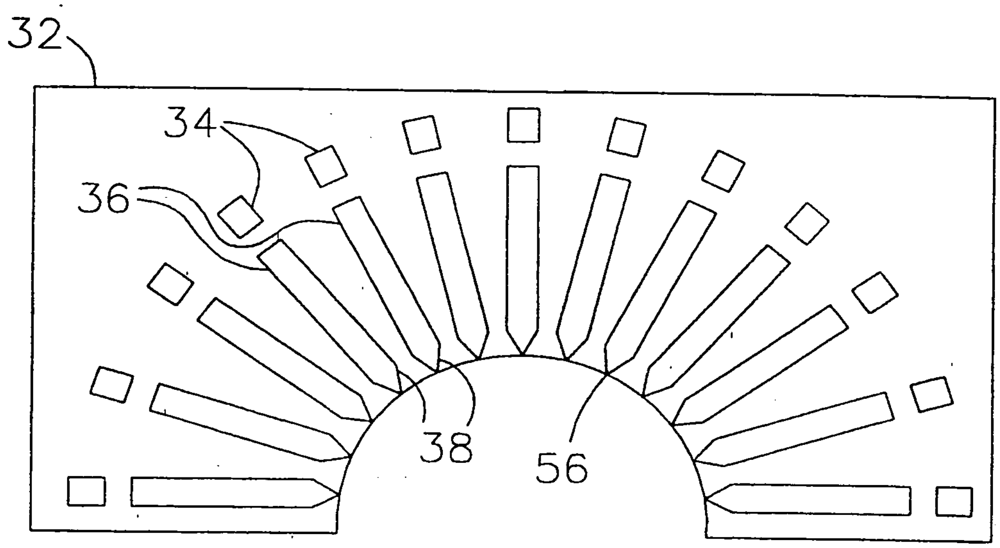

FIG. 10

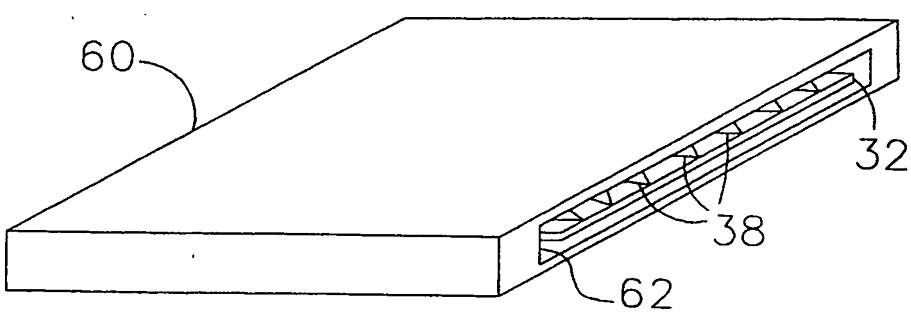

FIG. 11

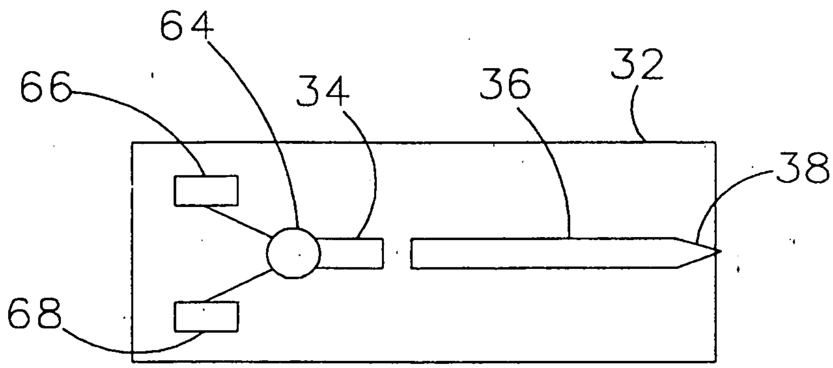

FIG. 12

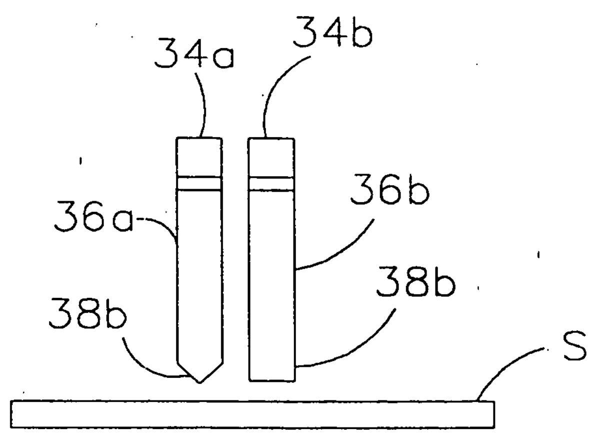

FIG. 13

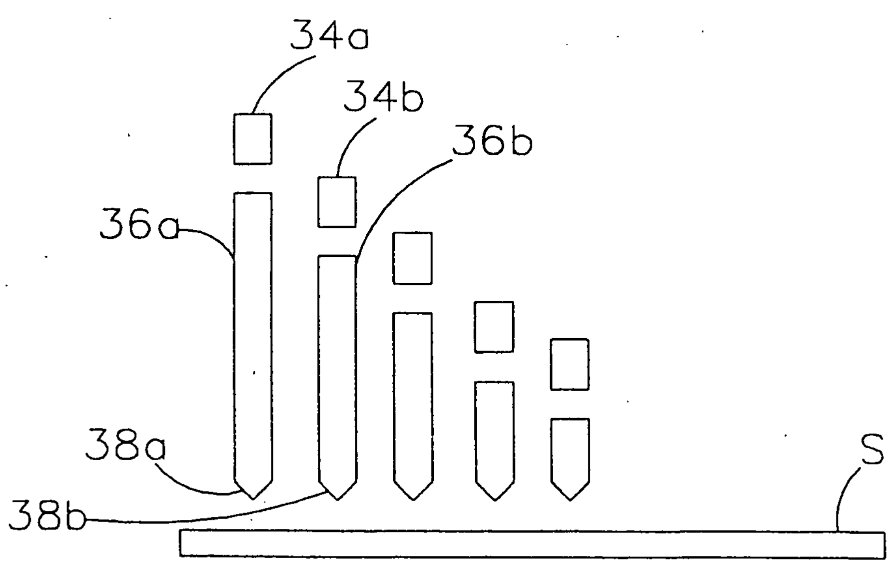

FIG. 14

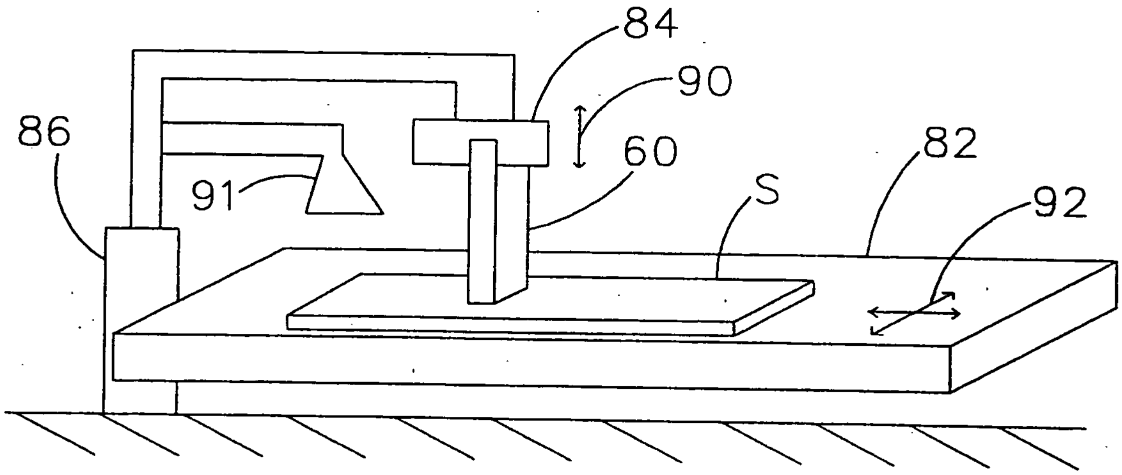

FIG. 15

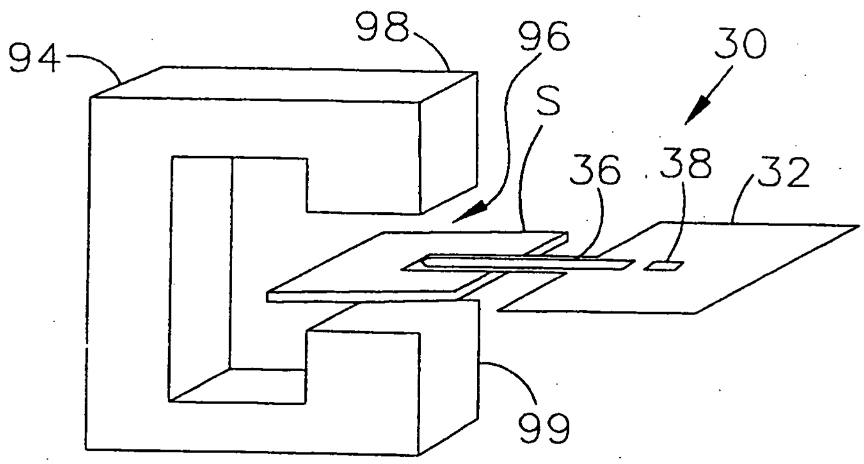

FIG. 16

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US99/14147

A. CLASSIFICATION OF SUBJECT MATTER
IPC(6) : G01N 22/00; G01R 27/04
US CL : 324/633, 635, 637; 343/700MS; 333/219
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
U.S. : 324/632, 633, 635, 636, 637, 638; 343/700MS; 333/204, 219, 227, 246, 247; 331/99, 107SL, 107DP; 73/105

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
none

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
none

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 4,782,297 A (SCHMALBEIN et al) 01 November 1988 (01.1.88), fig. 1.	14-19
Y	US 5,072,172 A (STOLARCZYK et al) 10 December 1991 (10.12.91), figs. 5 and 9.	1-13, 20-34
Y	US 5,416,490 A (POPOVIC) 16 May 1995 (16.05.95), fig. 1.	1-13, 20-34
Y	US 5,497,098 A (HEIL et al) 05 March 1996 (05.03.96), figs. 2 and 3.	1-13, 20-34
A,P	US 5,821,410 A (XIANG et al) 13 October 1998 (13.10.98), figs.1 and 4.	1-13, 20-34

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

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Date of the actual completion of the international search
07 November 1999 (07.11.1999)

Date of mailing of the international search report
17 NOV 1999

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